HYPERSPECTRAL OCEAN COLOR SCIENCE: SANTA BARBARA CHANNEL

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LONG-TERM GOALS

Our goal is to develop validation data sets for the modeling and interpretation of hyperspectral satellite ocean color imagery. This grant supports the addition of new optical measurements to the existing Plumes and Blooms (PnB) ocean color observation program. The goal of the PnB *in situ* sampling program is to develop state-of-the-art ocean color algorithms for Case II waters like those found in the Santa Barbara Channel. The PnB project is supported primarily by NASA. This work has filled the most glaring holes in the PnB *in situ* science program. This project provides a fundamental data set for the task of analyzing and modeling hyperspectral reflectance spectra in Case II waters. All PnB data are available via the world wide web (http://www.icess.ucsb.edu/PnB).

OBJECTIVES

Our near-term objectives are to validate hyperspectral determinations of remote sensing reflectance, determine *in vivo* absorption spectra for total particulate, dissolved and detrital particulate materials, deploy an *in situ* spectral transmissometer-reflective tube absorption meter, and analyze and interpret these data in conjunction with the rest of the PnB data set. The short-term science goal is to use these data to address the importance of absorption vs. backscattering in the variability of ocean color in Case II waters.

APPROACH

The approach of this grant is to provide supplemental support for the on-going PnB *in situ* science program to provide calibration and validation data sets for the analysis of hyperspectral reflectance spectra. Central to this is the determination of *in vivo* absorption spectra for total particulate ($a_p(\lambda)$), colored dissolved ($a_g(\lambda)$) and detrital particulate materials ($a_{det}(\lambda)$). From these measurements, determinations of the absorption spectrum due to phytoplankton abundances, $a_{ph}(\lambda)$, can be estimated ($a_{ph}(\lambda) = a_p(\lambda) - a_{det}(\lambda)$; figure 1).

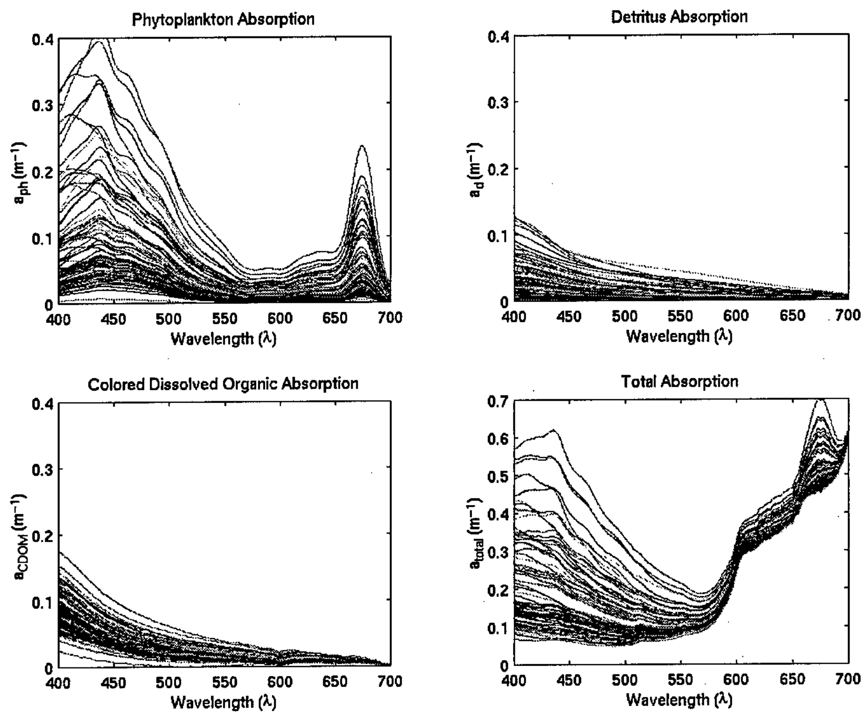

Figure 1: *In vivo* phytoplankton (upper left), detrital particulate (upper right), colored dissolved (lower left) and total (lower right) absorption spectra from the PnB program. All observations are shown which were taken between April 1997 and April 1999. The total absorption spectra ($a_{tot}(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{det}(\lambda) + a_g(\lambda)$) where the Pope and Fry [1997] $a_w(\lambda)$ estimates are used.

WORK COMPLETED

To date, we have fully implemented the field aspects of this grant. Since April of 1997, we have collected 357 stations of *in vivo* absorption spectra matched in time with hyperspectral estimates of remote sensing reflectance, $R_{rs}^{+}(\lambda)$. In addition, as part of every PnB station, samples are collected for inorganic nutrients, HPLC phytoplankton pigment analysis, fluorometric pigment analysis, total suspended solids, and biogenic and lithogenic silica concentrations.

We have also validated hyperspectral estimates of remote sensing reflectance (Toole et al. 1999). We show that the dominant portion of the variability in $R_{rs}^{+}(\lambda)$ spectra determined using above-water techniques is due to an incomplete removal of sky radiance. We developed a correction procedure for this effect by merging fixed band profiler and above-water hyperspectral estimates of $R_{rs}^{+}(\lambda)$ spectra (figure 2). The differences are striking and a manuscript on this method has been submitted to *Applied Optics*. As mentioned previously, all PnB data are available via the world wide web (http://www.icess.ucsb.edu/PnB).

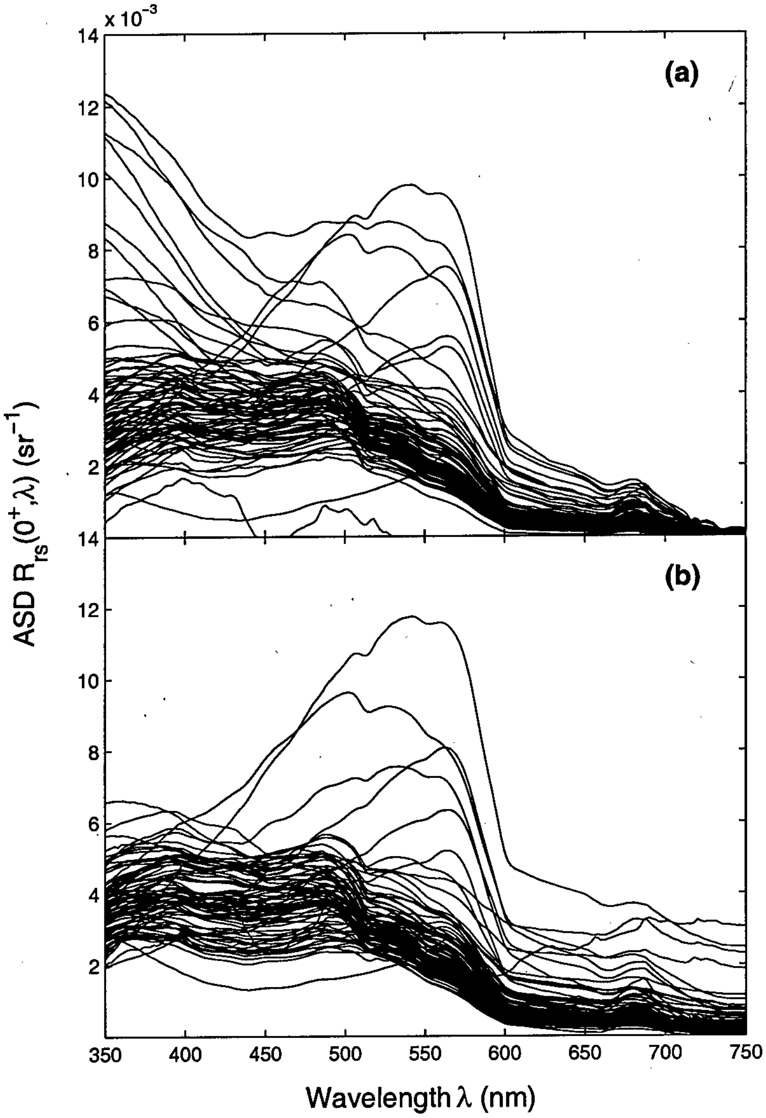

Figure 2: Before and after sky-radiance correction views of remote sensing reflectance spectra, $R^+_{rs}(\lambda)$, taken from the PnB observational program. All observations are shown which were taken between August 1996 and April 1998. The above-water, hand-held spectrometer technique is used alone in the upper panel and is merged with profiling spectroradiometer data in the lower panel. (Toole *et al.* 1999).

RESULTS

The Plumes and Blooms project has just entered its fourth year, and there are several important results to report. First, we have performed a detailed intercomparison of the

three independent methods for determining $R_{rs}^{+}(\lambda)$ (Toole *et al.* 1998;1999) These results have shown that the above-water hand-held spectrometer technique dramatically overestimates values of $R_{rs}^{+}(\lambda)$ under moderate to high wind conditions. Comparison with the profiling radiometer and tethered buoy derived $R_{rs}^{+}(\lambda)$ estimates indicate that the sky correction term required as part of the above-water spectrometer technique is under estimated by a factor of as much as 5. Although the sea surface on the average "sees" the same place in the sky under moderate wind speeds, the collected radiance from the water surface is contaminated not just by the simple reflected beam. This is because the sky radiance distribution is neither geometrically uniform nor slowly varying as a function of viewing angle. That is, the sky correction term cannot be simply modeled using existing procedures (Mueller and Austin, 1995) and improved sky correction procedures are required. A manuscript detailing these analyses and a correction procedure has been submitted for publication to *Applied Optics* (Toole *et al.* 1999).

Second, we have used our observations of $R_{rs}^{+}(\lambda)$ and $a_{tot}(\lambda)$ from the Santa Barbara Channel to assess the role of spectral backscattering and absorption on ocean color variability in Case II waters. Using the present observations of $R_{rs}^{+}(\lambda)$ and $a_{tot}(\lambda)$ (figures 1 and 2), estimates of spectral backscatter can be determined (e.g., Garver and Siegel, 1997). We have shown that variability in the reflectance spectra, $R_{rs}^{+}(\lambda)$, for the Santa Barbara Channel are to first order driven by values of particulate backscatter and to second order by the absorption coefficient, $a_{tot}(\lambda)$. This contrasts blue water sites, such as the Bermuda BioOptics Project (BBOP; Siegel *et al.* 1996), where the changes in the absorption coefficient regulate $R_{rs}^{+}(\lambda)$ variations in the blue to green portions of the spectrum. We are in the process of writing a manuscript describing the mechanisms of ocean color variations in a Case II environment like the Santa Barbara Channel (Toole *et al.* in prep.).

IMPACTS/APPLICATIONS

First and foremost, the impacts of this project will be in scientific progress. The effects of winds and surface waves on the sky correction term required for the above-water $R_{rs}^{+}(\lambda)$ estimates limits the utility of this technique to very calm days. Ours is one of the first detailed intercomparison studies of the various $R_{rs}^{+}(\lambda)$ determinations methods.

Second, the data collected here and the interpretations made using these data mark the scientific basis for developing semi-analytical ocean color algorithms for Case II waters. This work is also on-going and we anticipate significant breakthroughs in ocean color remote sensing capabilities. We have developed objective tuning methodologies for these models and the PnB data set will enable us to assess the importance of region in the design and implementation of ocean color algorithms. Last, all PnB data are available via the world wide web (http://www.icess.ucsb.edu/PnB).

TRANSITIONS

The present $R_{rs}^{+}(\lambda)$ intercomparison results have been presented to the NASA SIMBIOS program and have helped the planning of that program. We have provided code for our semi-analytical ocean color algorithms to Stennis NRL personnel and helped in their implementation into the SeaDAS system. We have also transitioned some of our algorithms for operational use in SeaWiFS data processing (Siegel et al. 1999).

RELATED PROJECTS

The Bermuda BioOptics Project (BBOP; Siegel *et al.* 1996) is supported by the NASA SIMBIOS program. It provides support for the UCSB calibration laboratory which is used extensively throughout the PnB project.

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